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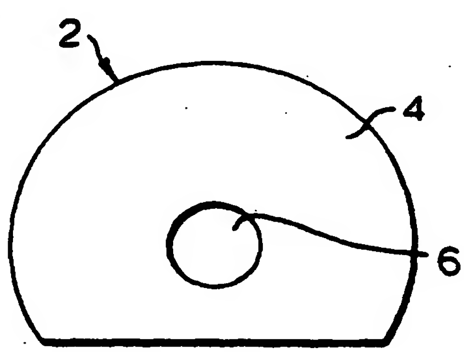
(54) Title: OPTICAL LIMITER



(57) Abstract: There is provided an optical power limiting device, including a waveguide section, having at least one core with an optical energy input end, an optical energy output end and cladding surrounding at least a portion of the core, the waveguide section including means affecting its properties upon being subjected to optical energy passing therethrough, which cause thermal changes in the core. A method for limiting the power transmitted through a waveguide is also provided.

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OPTICAL LIMITER

Field of the Invention

The present invention relates to optical power limitation, and more particularly, to an optical power limiting device and to a method for limiting power transmission through a waveguide.

Background of the Invention

Optical limiters are devices designed to have high transmittance for low level light inputs while blocking the transmittance for high power. Since the development of the first lasers in the late 60's passive optical limiters have been researched and concepts tested in order to protect optical sensors against laser peak-power induced damage. The first optical limiters for CW lasers were based on thermal lensing in absorbing bulk liquids, i.e. local heating reduced the index of refraction, causing "thermal blooming" and resulting in a beam that was no longer focused in an imaging system. Other methods such as two-photon absorption, self-focusing in Kerr liquids, nonlinear scattering from carbon particle suspensions in liquids have been suggested for pulsed laser sources limiting. While it is relatively easy to provide protection against a single wavelength, the wide availability of tunable laser sources requires that a practical limiter operates over a broad wavelength band. The device itself must also possess a high threshold against damage.

Laser light delivery through fibers for communications and other systems in medical, industrial and remote sensing applications, are recently handling relatively high powers, namely, optical powers from microwatts up to several watts, in single fibers or waveguides. Since these large, specific intensities of power per unit area are introduced into the systems, many of the thin film coatings, optical adhesives, and even the bulk materials, are exposed to light power beyond their damage thresholds and are eventually damaged. Another problem is the laser safety issue, wherein there are well-defined upper limits for the allowed powers emitted from fibers into the open air. These two issues call for a passive device that will limit the amount of energy propagating in a fiber/waveguide to the allowed level.

There have been many attempts to realize optical limiters, mainly for high power laser radiation, high power pulsed radiation, and eye safety devices. The techniques used in these devices were mainly:

1) Thermal lensing or "thermal blooming" in absorbing liquids, in which heating reduces the index of the liquid, causes thermal blooming, namely, liquid is hotter in the center of the beam and cooler towards the edges, forming a negative lens, resulting in a divergent output beam that is no longer focused on the detector, in e.g., an imaging system, i.e., effecting thermal change of the index of refraction n, in liquids having negative dn/dT, for defocusing the light beam.

2) Self-focusing or self-defocusing, due to high electric field-induced index of refraction n change, through the third order susceptibility term of the optical material, here $n=n_0+n_2E^2$, where n_0 is the index of refraction at zero electric field (no light), n_2 is the non-linear index change and E is the electric field strength of the light beam.

Both of the above techniques are non-linear and require very energetic laser beams or light intensities to produce a meaningful limitation. In the first technique, the volumes of liquid to be heated are large and need high powers, the bulk of liquid is not a good optical media and distorts the beam. In the second technique, the n_2 coefficient is very small for usable materials and requires very high electric fields. There are some other limiting effects, such as suspension of absorbing particles or power-induced absorption, which are in the same category. Limiting in fiber optics networks, either for CW radiation or for repetitive pulse radiation, as it appears in modulated radiation, involves lower peak, as well as lower average powers, and the techniques previously described are not adequate, since their effects are too small.

While it is relatively easy to provide protection against a single wavelength, the wide availability of tunable laser sources demands that a practical limiter operates over a broad wavelength band. The device itself must also have a high damage threshold.

Some work has been done on using liquid crystals as limiting material, mainly for high power pulses, but the transparency of these materials and their optical quality is not high enough for use in fiber optics communication.

Disclosure of the Invention

It is therefore a broad object of the present invention to provide an optical power limiting device and a method for limiting power transmission through a waveguide, which ameliorates the disadvantages of the prior art devices and methods.

In accordance with the present invention, there is therefore provided an optical power limiting device, comprising a waveguide section, including at least one core having an optical energy input end, an optical energy output end and cladding surrouding at least a portion of said core said waveguide section including means affecting its properties upon being subjected to optical energy passing therethrough, which cause thermal changes in said core.

The invention further provides A method for limiting the power transmitted through a waveguide consisting of a core and cladding, said method comprising forming said core selected from a group of materials producing a change of properties of said core with a change of temperature to which the core is subjected symmetrically or asymmetrically cladding at least a portion of said core, so as to form a waveguide section, and coupling said waveguide section in a waveguide line transmitting optical energy therethrough, wherein a change in temperature of said core which causes a change in at least one of said properties limits the optical energy transmitted through said waveguide.

The optical power limiting device according to the present invention has the following properties and advantages:

1. The operation of the limiter is passive; no external power is required.
2. When the light power transmitted through the device reaches a predetermined threshold, the device acts as a limiter, i.e., limiting the output power to the predetermined maximum.
3. The predetermined threshold of the limiter can be tested periodically, or on demand.

4. The device operates for many cycles, limiting at high input powers and returning to its original, non-limiting state when the input power is lowered or shut off.
5. The device is activated by a broad range of wavelengths, e.g., 980, 1300, 1500 nm. It may have small differences in materials and dimensions to fit the right spectral range.
6. The device withstands high intensities a few times higher than the limiting threshold.
7. The device has relatively fast response, limited by the direct or indirect heating time of minute volumes.
8. The device has high spectral transmission at intensities below the limiting threshold.
9. The device is suitable for use as an in-line fiber insert (like a patch cord), for single or multi-mode fibers, or for fiber lasers.

Examples of possible uses of the limiter according to the present invention are utilization of the optical power limiting devices in the area of optical communciation, e.g., as detector protectors, switch and line protectors, amplifier input signal limiters and equalizing and power surge protection. The limiters can also be utilized in the areas of medical, military and laser machining, e.g., power power surge protection and safety.

Brief Description of the Drawings

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is

necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

Figs. 1 and 2 are cross-sectional views of two possible waveguide sections constituting optical power limiting devices, according to the present invention;

Figs. 3 to 6 are cross-sectional views of different embodiments of optical power limiting devices, according to the present invention;

Figs. 7 and 8 are side views of still further embodiments of the present invention;

Fig. 9 is a cross–sectional view of an indirect heating optical power limiter, according to the present invention, and

Fig. 10 schematically illustrates a Thermo Electric Cooler/Heater control of an optical power limiting device, according to the present invention.

Detailed Description

Figs. 1 and 2 are cross-sectional views of two possible configurations of waveguide sections 2, e.g., optical fiber sections. The device is constituted by cladding 4 surrounding a core 6. The cladding 4 may be made of silica or glass and the core 6 of a suitable polymer. As seen, waveguide sections 2 are tubular and non-symmetrical, in the sense that the cladding 4 surrounds the core asymmetrically.

Figs. 3 to 6 illustrate cross-sectional views of various embodiments of the optical power limiting device of the invention. Shown is a waveguide section 2, having an optical energy input end 8 and an optical energy output end 10. The device is affixed at its input end 8, e.g., to a base 12, by any coupling means 14, leaving the output end 10 free to move. Output end 10 is disposed adjacent to a non-movable, tubular waveguide section 16 having a core 18 axially aligned with the core 6 of waveguide section 2.

In operation, upon the transmission of optical energy through the asymmetrical waveguide section 2, thermal changes are caused in view of the partial absorption of the light in the core 6, and its Coefficient of Thermal Expansion. Due to the asymmetrical configuration of the waveguide section, it expands asymmetrically and,

in turn, deflects and moves in the direction of the arrow. The deflection forms a lateral and angular misalignment between the cores 6 and 18, limiting the amount of energy transmitted through waveguide section 16.

A modification of the embodiment of Fig. 3 is shown in Fig. 4. Here, in order to enhance the effect of relative movement between portions of a transmission line, there are provided two asymmetrical movable waveguide sections 2,2′, disposed face-to-face in opposite directions. The arrows clearly indicate the direction of movement of each section.

The embodiments of Figs. 5 and 6 correspond to those of Figs. 3 and 4, except for the input/output interfacing surfaces 20,22 of the waveguide sections 2,16 and 2, 2′. The angular cut of the interfacing surfaces 20,22 may improve the sensitivity of the device.

Referring now to Fig. 7, there is illustrated a curved waveguide section 2, provided with a curved core 26 and cladding 28. The core 26 may be made, e.g., of a polymer having a negative change in the index of refraction n when the temperature T increases, i.e., a negative dn/dT, namely, the index of refraction is lowered when the temperature increases. When the optical energy is transmitted through the core, the core is heated due to absorption of optical light. When energy passes a predetermined threshold, the heat absorbed in the core will cause the lowering of the index of refraction, which, in turn, will cause the leakage of optical energy into the cladding 28. This effect can be enhanced by selecting cladding material having a positive dn/dT, e.g., silica or glass. The curved waveguide configuration of Fig. 7 is more suitable for transmission of lower energies, as the optical leakage in such a configuration commences at lower powers compared with the leakage threshold of a linear waveguide configuration.

Fig. 8 illustrates an "S-type" configuration of the core of a waveguide section 2, constituted by a curved core 30 embedded in cladding 32. The same waveguide configuration may be provided with a detector 34 attached thereto for detecting the optical energy refracted from the adjacent core portion, thereby forming a signal utilizable for warning, monitoring and feedback purposes.

Fig. 9 illustrates a linear waveguide section 2 wherein the core 36 has a negative dn/dT, but its absorption is not high enough to create a large change in the index of refraction. In this case, several heat absorbing layers 38, e.g., thin metallic layers of gold, silicon, nickel, chrome, or the like, are deposited in spaced-apart relationship along the waveguide, and when heated, the heat to the non-absorbing core 36 and cladding 40, is transferred by conduction. In this case, the materials of the waveguide section need to have only the right dn/dT (negative in the core 36 and positive in the cladding 40), and the heat absorbing layers 38, supply the heat indirectly. Anti-reflecting coatings (not shown) to minimize back reflections covering the heat absorbing layers 38, may be provided.

Fig. 10 illustrates an optical power limiting device, according to the present invention, thermally disposed in a controllable temperature chamber 42. The chamber 42 controlled by a thermo-electric cooler/heater 44, in which the heat is driven to or from a heat sink 46. When the core 48 of the device has a negative dn/dT and the cladding 50 has a positive dn/dT, the initial difference between the core index of refraction n of the cladding 50 is determined by the temperature of the whole assembly. In this way, the temperature set by the thermo-electric cooler/heater 44 controls the limiting threshold, which depends on the difference in index of refraction n between the cladding 50 and the core 48.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

CLAIMS

1. An optical power limiting device, comprising:

a waveguide section, including at least one core having an optical energy input end, an optical energy output end and cladding surrouding at least a portion of said core,

said waveguide section including means affecting its properties upon being subjected to optical energy passing therethrough, which cause thermal changes in said core.

2. The device as claimed in claim 1, wherein said properties are selected from the group including deflection of at least a portion of said waveguide section and/or variations in the index of refraction of at least a portion of said core.

3. The device as claimed in claim 1, wherein said means affecting the properties of the waveguide section are selected from the group including non-symmetry of at least a portion of said cladding and/or the index of refraction of said core.

4. The device as claimed in claim 1, wherein at least a portion of said cladding is asymmetric with respect to said core.

5. The device as claimed in claim 1, wherein said core and/or cladding have a negative or positive refractive index change when subjected to a change in temperature.

6. The device as claimed in claim 1, wherein said waveguide section is linear.

7. The device as claimed in claim 1, wherein said core is at least partially curved.

8. The device as claimed in claim 4, wherein said waveguide section is affixed at one of its ends, facilitating movement at its other end when subjected to thermal energy causing thermal changes in said core.

9. The device as claimed in claim 8, comprising two waveguide sections adjacently disposed in linear orientation, one end of each of said sections being affixed at its input end or output end, so as to allow the free ends to move with respect to an affixed end.

10. The device as claimed in claim 9, wherein the ends of said two adjacent sections are cut at an angle relative to the axis of said cores.

11. The device as claimed in claim 1, wherein said core is S-shaped.

12. The device as claimed in claim 1, wherein said waveguide further comprises a detector attached to the cladding for detecting optical energy refracted from an adjacent core portion.

13. The device as claimed in claim 1, wherein said core is at least partially absorbing.

14. The device as claimed in claim 1, wherein the core and cladding are indirectly heated by one or more heat absorbing layers located in spaced-apart relationship along the waveguide section.

15. The device as claimed in claim 1, wherein said core has a negative dn/dT and the cladding has a positive dn/dT, and the limiting threshold or the difference between the core index of refraction and cladding index of refraction is controlled by the initial temperature of said core and cladding, as set by a thermo-electric cooler/heater, in which said device is disposed.

16. A method for limiting the power transmitted through a waveguide consisting of a core and cladding, said method comprising:

forming said core selected from a group of materials producing a change of properties of said core with a change of temperature to which the core is subjected;

symmetrically or asymmetrically cladding at least a portion of said core, so as to form a waveguide section, and

coupling said waveguide section in a waveguide line transmitting optical energy therethrough, wherein a change in temperature of said core which causes a change in at least one of said properties limits the optical energy transmitted through said waveguide.

17. The method as claimed in claim 16, wherein the material of said core is selected to cause a change in its coefficient of expansion and/or a change in its index of refraction.

18. The method as claimed in claim 16, wherein said change in temperature is caused by optical energy transmitted through said core exceeding a predetermined threshold.

19. The method as claimed in claim 16, comprising:

providing two waveguide sections adjacently disposed in linear orientation, and

affixing at least one end of each of said waveguide sections, so as to only allow movement of a second end of at least one of said waveguides with respect to an affixed end.

20. The method as claimed in claim 16, further comprising the step of configuring at least the core of said waveguide section in a form of a curve.

21. The method as claimed in claim 16, further comprising the step of configuring at least the core of said waveguide section in a form of the letter "S".

22. The method as claimed in claim 16, further comprising placing said waveguide in a thermoelectric cooler/heater to set the waveguide temperature prior to operation.

Fig.2.

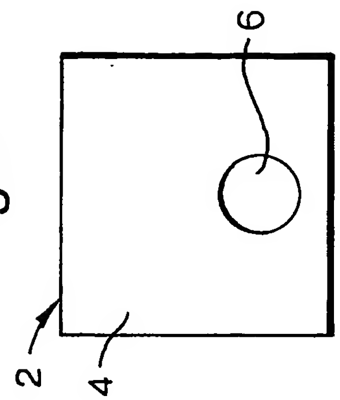


Fig.1.

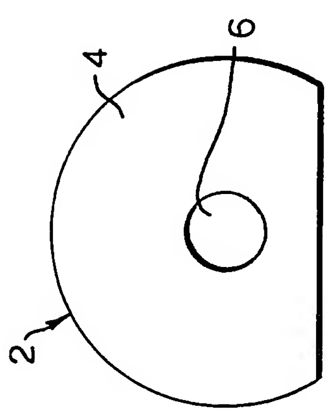
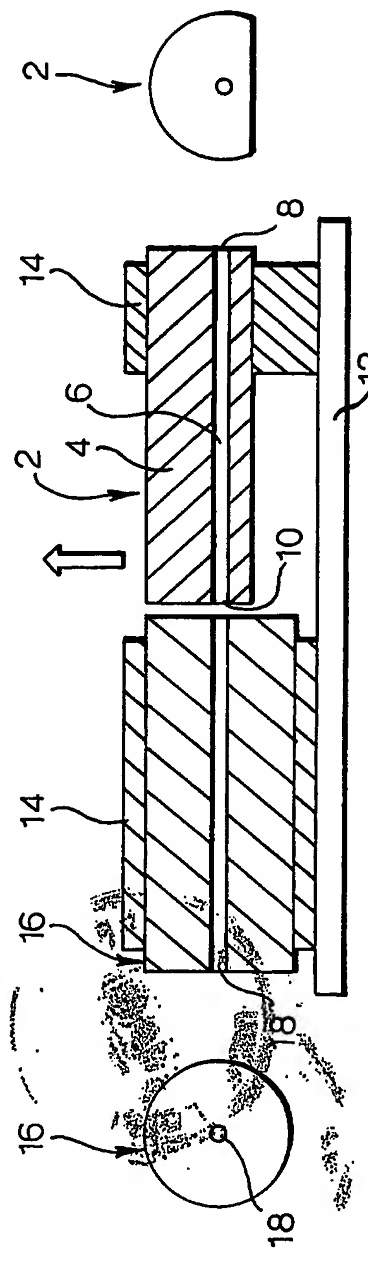


Fig.3.



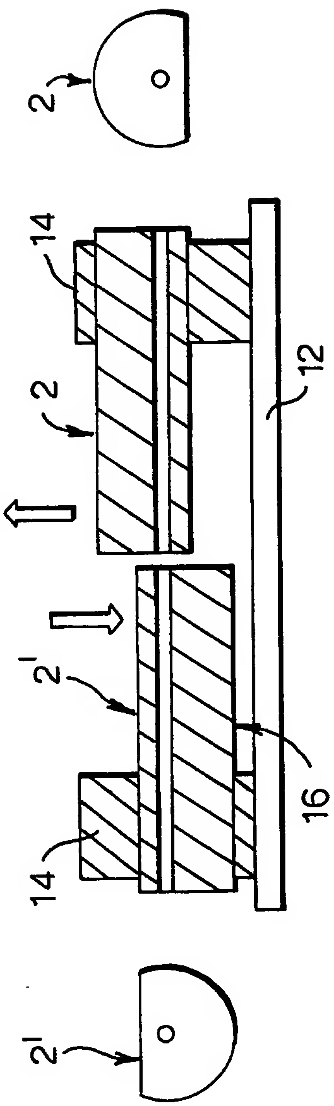


Fig.4.

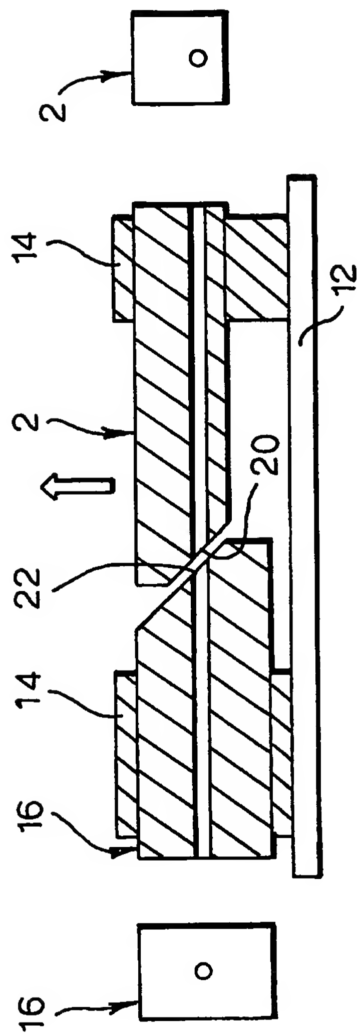


Fig.5.

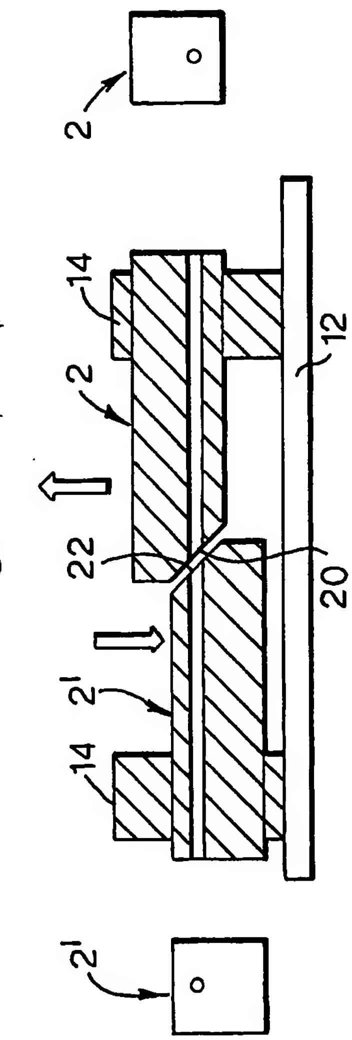


Fig.6.

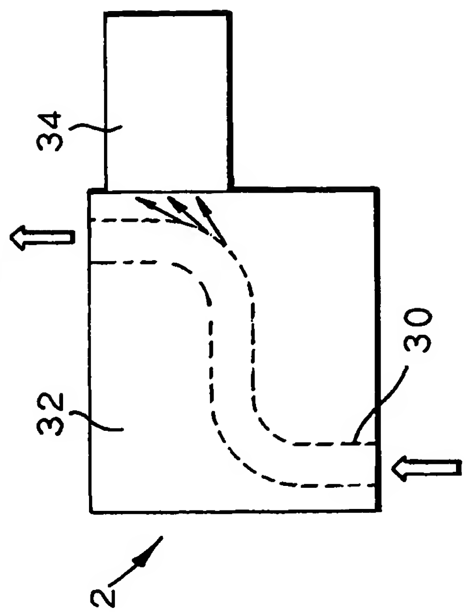


Fig.8.

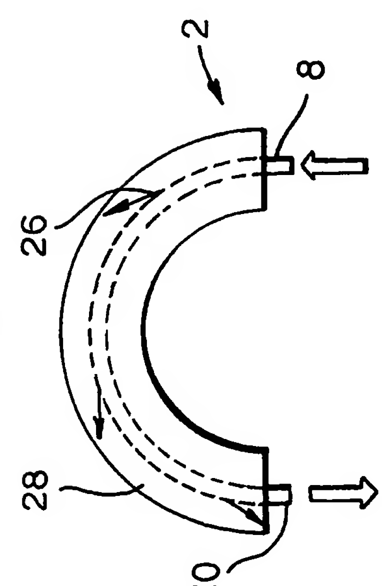


Fig.7.

Fig.9.

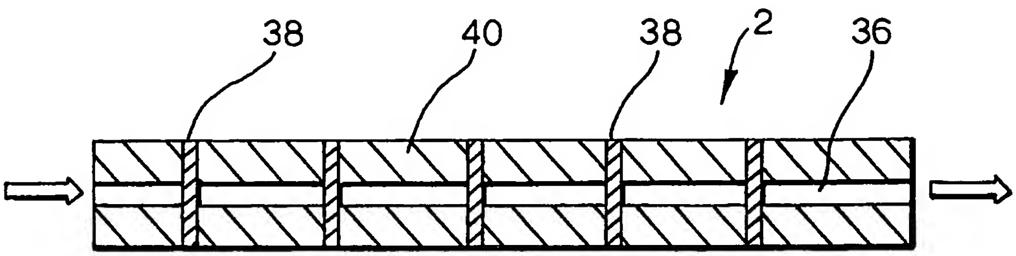


Fig.10.